Electro-acoustic estimation of the compensatory method of electric motor noise decrease

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Abstract

Electromagnetic interaction between stator and rotor fields, mechanical motor vibrations and air fluctuations from ventilation motor impeller compose the basic components of electric motor noise in a wide frequency range. Magnetostrictive forces causing radial deformation of the stator core rings under alternate field action bring the special addition in motor noise in basic 100 Hz frequency. The compensation method consists on reduction 100 Hz frequency and its harmonics as an interference interaction between two antiphase sources is considered. The air volume formed by the winding stator and several rotor core elements is fluctuated. External side of stator magnetic core is appeared as first source and internal side of stator magnetic core is applied as second source influencing fluctuations through the hole drilled in bearing motor side with an allowance for adding the short pipe used as resonant cavity. The most compensation effect in 100 Hz frequency as close as possible to resonant frequency of resonator is fixed. The asynchronous electric motor into the small volume chamber SVC with rubber damping construction is installed. The greatest linear size SVC less than half of wave length of the longest eighen frequency is used. Interaction between external side of stator magnetic core and resonant source into SVC is modeled on the forepole system with coefficient taking into account the difference between areas of both sources by transformation coefficient. The dependence of the sound noise pressure from electromagnetic vibrations inside of the SVC with and without compensation effect is considered. The spectrograms illustrating of magnetic motor noise decrease are shown and the adjustment for decrease of magnetic motor noise is supported.

1 Formulation of the problem of the motor noise reduction

The increase quantity and power of electric machines and aspiration to facilitate designs cause increased requirements to noise machine characteristics which in the list of the basic parameters of quality are included. First of all it is caused by harmful influence of noise on a person.

Not expensive but most applied asynchronous electric motors with such basic noise components as magnetic, mechanical and aerodynamic with typical ventilation systems are used. The stator core fluctuations by the magnetostrictive forces are excited. During each half of a cycle of alternative electrical field the stator core has one compression-stretching cycle. The doubling network frequency corresponding of mechanical fluctuations 100 Hz is prevailed.
The main idea is to reduce of electric motor noise by negative correlation of a pier of sound harmonic sources: stator core 100 Hz fluctuations and resonator with antiphase 100 Hz fluctuations. Therefore the motor installed into the small volume box (SVB) having the maximum size not more than half of air wave length corresponded the double frequency network 100 Hz are investigated. Thus acoustical field as statistical is considered when the level of sound pressure is the same in all points of the SVB and does not depend on coordinates. It is exact restriction for low frequencies while eighen frequencies of the SVB considerably above frequencies investigated are excited [1].
The effect of acoustic short circuit is well known especially for developing of a loudspeaker enclosure. The corresponding sound pressure excited by alternative cycles of air compression-stretch of the opposite loudspeaker diaphragm surfaces are created. If loudspeaker acoustic baffle is absent the effect of acoustic short circuit in low frequencies is happened because of the diffraction of sound waves. In this way the sound pressure in surrounding space is decreased.
The similar acoustic effect to reduce of low frequency electric motor noise is applied. The reduction of the basic magnetic noise component with carrying frequency 100 Hz in broadband spectrum of pressure is examined [2].

2 Acoustic - mechanical system

Some air capacity inside of the electric motor formed by winding stator and rotor elements is considered. The aperture S_2 through a motor beating side for passing out internal stator core fluctuations was drilled. The internal stator core fluctuations with external stator core fluctuations being antiphase each other are summarized. Then motor noise pressure into SVB as result of the interference of such fluctuations is decreased (Fig.1).
The aperture with the piece of a pipe installed as a resonator throat is supplemented. The construction on rubber shock-absorber into SVB was fixed.
The installation for analysis of magnetic noise reduction including the SVB with the linear sizes 0,4m 0,5m 0,6m and the asynchronous electric motors 800 Wt was developed.
Application of the resonator system allows forcing sound radiation in the resonant frequency 100 Hz by ratio determined as

$$f_{@} = \frac{1}{\sqrt{m_2 \cdot c_a}} \tag{1}$$

Here*m2* is the sum of air weight in the resonator throat and the air weight of environment;*ca* is air flexibility in the SVB divided to aperture*S2, S1* is the fluctuation surface of the stator core.

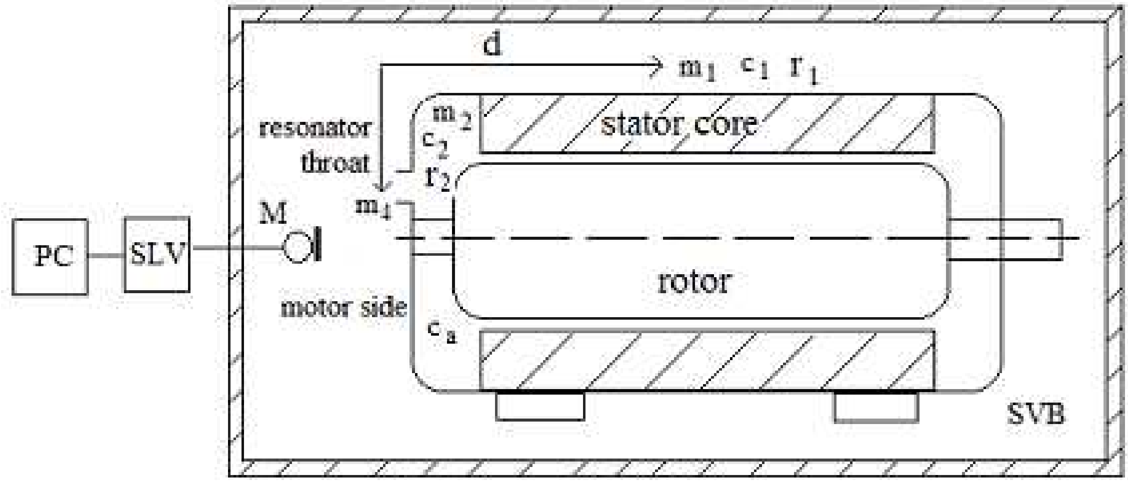

Figure 1: Installation for analysis of magnetic noise reduction: *M* is the microphone with the amplifier; *SLV* is the sound level meter; *PC* is the computer; *d* is distance between centers of sources

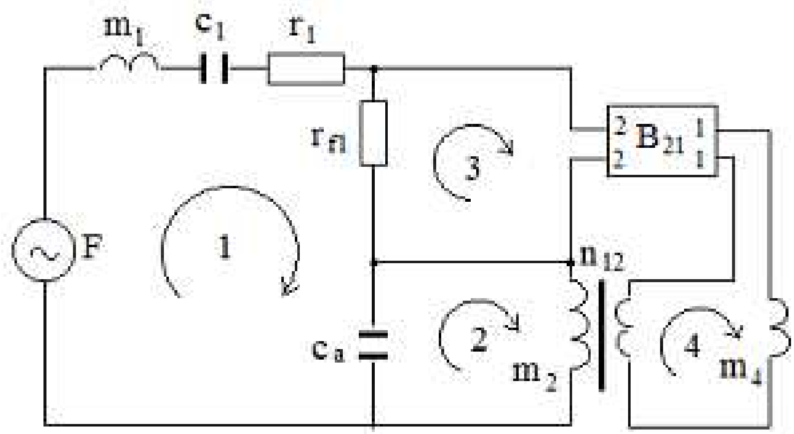

Figure 2: Equivalent electric scheme showing interactions of four contours between stator core and resonator with the aperture S2 into SVB

The internal stator core fluctuations by flexibility *ca* to air weight *m2* are transferred. So *m2* serves as the second radiator. On the resonant frequency of the resonator with aperture S2 *f =fres* or frequencies as close as *fres* the fluctuations of weight *m2* achieve the highest amplitudes.

The equivalent electric scheme acoustic-electrical system on Fig.1 is considered and allowing to estimate quantitatively the interaction of fluctuations between stator core and resonator into SVB.

The contour 1 in Fig.2 is the basic source of excitation (external stator core fluctuations) with oscillatory speed $\dot{\xi}_1, m1, c1, r1$.

By contour 2 in Fig.2 the fluctuations with the oscillatory speed $\dot{\xi}_2$ between equivalent air weight inside electric motor and air weight in the resonator throat are considered.

By contour 3 in Fig.2 the interaction with the oscillatory speed $\dot{\xi}_3$ between external

stator core radiations and air resistance into SVB is considered.
By contour 4 in Fig.2 the fluctuations with the oscillatory speed $\dot{\xi}_4$of air weight in SVB oscillating in common with air weight of resonator throat are considered.

3 Interpretation of the interaction between stator core and resonator fluctuations

Interaction between stator core and resonator fluctuations by two-port network *b21* (Fig.2) with transfer coefficient is modeled

$$b_{21} = \frac{\dot{\xi}_3}{\dot{\xi}_4} = \frac{S_2}{S_1} e^{-jkd} = n_{21} e^{-jkd}. \tag{2}$$

The difference between of the areas stator core S1 and the aperture S2 of the resonator by transfer coefficient *n21* and the delay of a stream $\dot{\xi}_2 S_2$ from the aperture on a way d with a phase member e^{-jkd} is considered.
The main parameter explaining the interaction between stator core and resonator in Fig.2 is the common radiation resistance *rf*. Then the *rf* can be determined as the sound radiating power W in common fluctuations of the stator core and the resonator with aperture S2by two ways: with oscillatory speed $\dot{\xi}_1$ stator core ore as the difference $\dot{\xi}_1 - \dot{\xi}_3$. Then

$$W = \left|\dot{\xi}_1\right|^2 \cdot r_f = \left|\dot{\xi}_1 - \dot{\xi}_3\right|^2 \cdot r_{f1}, \tag{3}$$

thus

$$r_f = r_{f1} \left|1 - \frac{\dot{\xi}_3}{\dot{\xi}_1}\right|^2. \tag{4}$$

In these expressions*rf1* is the resistance of fluctuation of stator core radiation without an aperture in motor but *rf* is with an aperture. For finding*rf* from (3) the scheme on Fig.2 is used.
The following features of the scheme in Fig.2 are taken into account. The resistance*rf1* and the target resistance of the two-port network *b21* parallel connected with *rf1* between points *2-2* are summarized as the resistance*rf*.
The entrance resistance between points *1-1* of the two-port network *b21*is the same as target resistance but in n_{21}^2 time increased. At recalculation in the contour 2 with oscillatory speed $\dot{\xi}_2$ the active resistance is*rf* and the reactive resistance is $\omega m_2 = \omega m_4 n_{12}^2$. Here $\dot{\xi}_2$is the speed determined to aperture*S2*.
Considered from this point of view the expression is found

$$\frac{\dot{\xi}_2}{\dot{\xi}_1} = \frac{1}{j\omega c_a \left(r_f + j\omega m_2 + 1/j\omega c_a\right)} = \frac{1}{j\omega c_a Z}, \tag{5}$$

were $Z = r_f + j\omega m_2 + 1/j\omega c_a$.
In the other side according (2) and taking a form as $e^{-jkd} \approx 1 - jkd$ the expression $\dot{\xi}_4 \approx \dot{\xi}_3 / \left(1 - jkd\right)$ is found.

Thereby

$$1-\frac{\dot{\xi}_3}{\dot{\xi}_1}=\frac{r_f+j\omega m_4+kd/\omega c_a}{Z}. \qquad (6)$$

The numerical $\frac{kd}{\omega c_a}=\frac{d}{c_0 c_a}=\rho_0 c_0 \frac{d\cdot S_1^2}{V} \gg r_f$ being of value in (7) is used.
Here V is the air volume into electric motor, co is the sound speed in air, ca is the air flexibility into electric motor (Fig.1).
Neglecting r_f and substituting the module (5) in (4) the common radiation resistance rf is received

$$r_f=r_{f1}\frac{(d/c_0 c_a)^2+(\omega m_4)^2}{r_f^2+(\omega m_4-1/\omega c_a)^2}. \qquad (7)$$

To find out numerical value rf du to three frequency ranges $\omega \gg \omega_{res}, \omega \ll \omega_{res}, \omega = \omega_{res}$the expression (7) is investigated. Here ω_{res} is the resonant frequency of the resonator.
If the first frequency range is $\omega \gg \omega_{res}$then $\omega m_2 \gg \frac{1}{\omega c_a}, \omega m_2 \gg \frac{d}{c_0 c_a}$ and after some simplifications the expression (7) is transformed

$$r_f \approx r_{f1}. \qquad (8)$$

If the second frequency range is $\omega \ll \omega_{res}$ then $\omega m_2 \ll \frac{1}{\omega c_a}, \omega m_2 \ll \frac{d}{c_0 c_a}$ and after simplifications the expression (7) is transformed

$$r_f \approx \frac{\rho_0}{4\pi c_0^3} d^2 S_1^2 \omega_{res}^4. \qquad (9)$$

The third expression $\omega = \omega_{res}$ is more important. Then $\omega_{res} m_2 > \frac{d}{c_0 c_a}$ and after simplifications the expression (7) is transformed

$$r_f \approx \sqrt[3]{r_{f1}\cdot \omega_{res}^2 m_2^2}. \qquad (10)$$

4 The results of measurements of the acoustic short circuit effect for motor noise reduction

For discussion about acoustic short circuit effect there are two motor noise pressure spectrograms into SVB: without the resonator (Fig.3) and having the resonator with aperture S2 in motor side (Fig.4).
The frequency on abscissa (Hz) and the relative acoustic noise pressure (dB) on ordinate axis are constructed. The integrate level noise pressure 89 dB measured by sound level meter $RFT0024$ was fixed (Fig.3). The maximum noise pressure value is corresponding of the basic magnetic motor noise frequency 100 Hz.
The frequency on abscissa (Hz) and the relative acoustic pressure (dB) on ordinate axis are constructed. The acoustic short circuit effect for motor noise reduction used in the frequency 100 Hz and the first harmonics in Fig.4 is shown. The integrate level noise pressure 82 dB measured by the sound level meter was fixed.

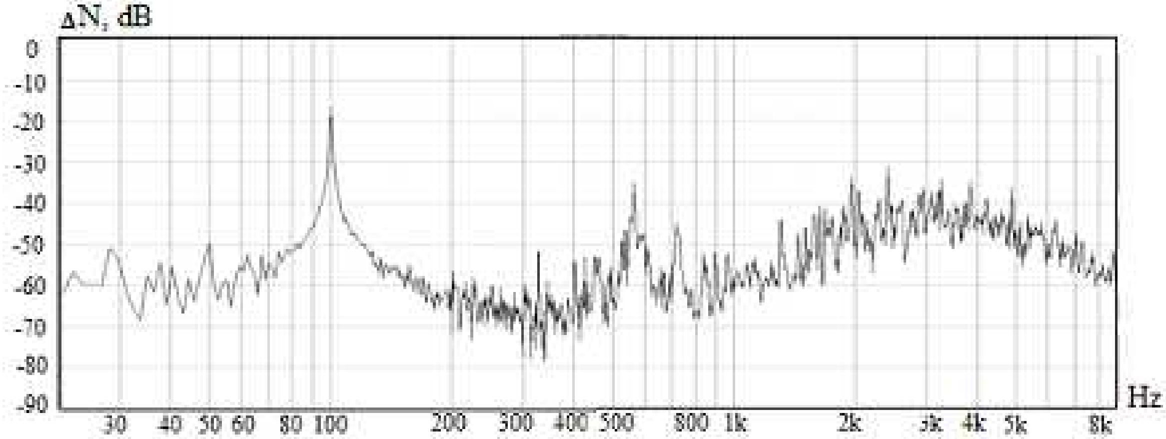

Figure 3: Noise pressure spectrogram for motor without resonator

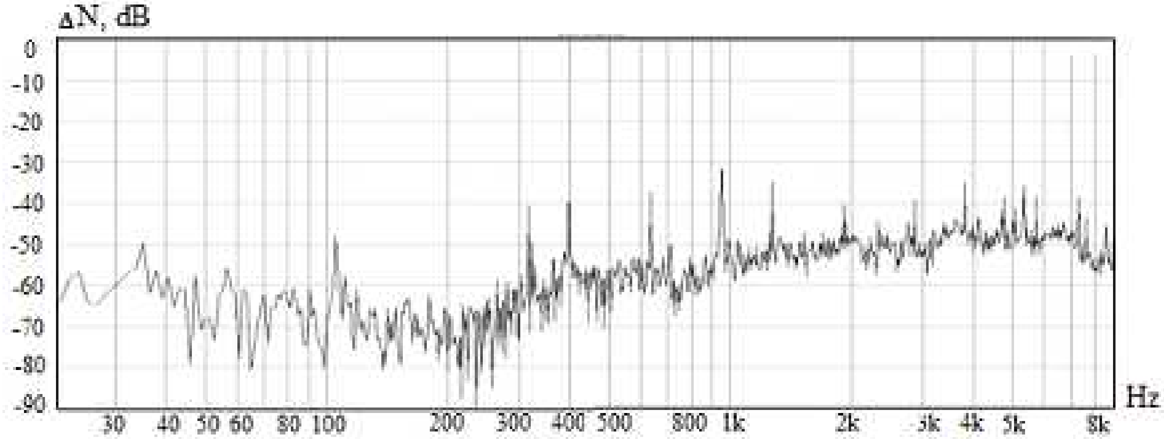

Figure 4: Noise pressure spectrogram for motor having the resonator with aperture S2 in motor side

Comparing spectrograms in Fig.3 and in Fig.4 the integrate level pressure from 89 dB (without resonator) to 82 dB (with resonator) in wide strip is decreased.
As follows from stated the effective method developed making quieter electric motors for person protection in low frequencies and increasing functions of power electronics on transport is provided.

References

[1] Davydov V. V., Kolykhalin V. M. About compensation method of the electric motor noise.- B.: Vestnik BGTU named V.G. Shukhov, 2014.

[2] Kolykhalin V.M., Davydov V.V. Device of the electric motor noise compensation. Patent of the Russian Federation є2528552, M. Federal serv., RU RU 2528552 C1, published 20.09.2014 Bul. 26.