Development of families of acoustic radiation attenuation technical devices of closed type electric transformer substation

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Abstract

The article presents the development of families of original technical devices of acoustic radiation attenuation produced by the active part of power electrical transformer and its ventilation cooling, which involve the use of various types of frequency- and temperature- tuned acoustic resonators (quarter-, half-wave, Helmholtz), presented both as a single (autonomous) acoustic resonators, and as an interlocked multiple similar and/or different types of acoustic resonators formed compact prefabricated assemblies of acoustic resonators battery type.

Power electrical transformer may be a significant source of acoustic (noise) pollution, not only of open space settlements residential areas, but also of production, public or residential areas with the biological objects (people, animals). According to published information materials [1...4], the main (dominant) sources, the active part of an electrical transformer in the form of magnetic core and isolated windings, covered a total flux, and the system (device) ventilation cooling of its active part are the generating sound radiation (noise) electric power. Significant influence on the amplification of a power electric transformer noise emission can be made by dynamic resonance phenomena, manifested in the form of mechanical vibrations arising in its constituent parts - coolers, oil tank walls, expander, pipelines. Mechanical vibrations of the active part of the power electrical transformer are due to variable magnetostrictive, and electromagnetic forces arising in the magnetic system and the variable dynamic forces in isolated windings. In this case the dominant vibration actuating force is the magnetostrictive component. In a circuit of alternating current with frequency $f_{AC}=50$ Hz for induction values more than 1.4 Tesla, magnetostrictive

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component appears at multiples harmonics $f_1 = 2f_{\text{AC}} = 100$ Hz, $f_2 = 4f_{\text{AC}} = 200$ Hz and $f_3 = 6f_{\text{AC}} = 300$ Hz. When the magnetization reversal of the active part of electric transformer magnetic induction it reaches a maximum twice per period of the alternating current circuit frequency, which corresponds to twice a dynamic change in length of steel sheets of the magnetic circuit (magnetic system). In particular, this caused the periodical fluctuation of the magnetic system with the double frequency ($f_1$) in connection with the frequency of the AC ($f_{\text{AC}}$), and a multiple harmonics $f_2$ and $f_3$.

Being used noise emissions reducing technical devices, produced by power electric transformers do not only relate to constructive revisions of directly constituent elements of the power electric transformers, but also to the use of technical premise improved constructions, where the power electrical transformers with the formation of low-noise electric transformers substations of closed type (see. Fig. 1) are located.

Obviously, the power electric transformer noise radiation, which effects the discrete functional operating frequencies $f_1$, $f_2$, $f_3$ (where $f_{\text{AC}} = 50$ Hz - the frequency of the AC power, connected to an electricity transformer) can be suppressed by using of the appropriate type of acoustic resonators $R_1$, $R_2$, $R_3$, configured on given discrete values of sound frequencies $f_1$, $f_2$, $f_3$. There are three types of acoustic resonators $R$ - quarter wave acoustic resonators $R'$, half-wave acoustic resonators $R''$ and a Helmholtz resonator $R'''$ (see. Fig. 2), known in technical acoustics and widely used in practice [5…10].

The first two types of acoustic resonators $R'$ and $R''$ are the resonators of tubular type, the principle of which is based on the phase interference suppression of the sound waves energy at the resonance frequency of the resonators $f_R$. Their precise frequency setting provides an appropriate choice of dynamic length of tubular parts ($l'_R$, $l''_R$), supplies the complementary addition of amplitude of the sound waves of a given length (quarter or half wavelength),
spread in opposite directions in their tubular parts. To ensure effective antiphase compensation of the sound pressure amplitude values in the cavity of the tubular portion of a half wave acoustic resonator $R''$ with the set value of the dynamic length of $l''_R$ in the frequency range of 100...300 Hz, covering the work functional frequencies $f_1$, $f_2$, $f_3$, it is necessary for the shortest distance $\gamma$ between the flow passages of the ending parts of the tubular portion in the area of the open throats of half wave acoustic resonator $R''$ not to exceed 0.1 m. In this case, a sound wave cophased inclusion in both throat portions of the acoustic resonator $R''$ with its subsequent antiphase compensation in the middle zone of the tubular part is provided.

![Diagram](image)

Figure 2 - Scheme of interlocked modular units composed of three identical acoustic resonators $R_1$, $R_2$, $R_3$ (a – quarter, b – half-wave, c – Helmholtz) with defined damping elements

8 - tubular portion; 9 - the bottom part (acoustically reflective rigid bedplate); 10 – perforation holes; 11 – air-swept damping porous plug; 12 - a throat part; 13 - protective footer snubber air-swept layer; 14 - a chamber part
At constant (unchanging) frequency discrete values of sound radiation $f_1, f_2, f_3$, the accuracy of the frequency tuning of acoustic resonators $R'$ and $R''$ is predetermined by the specific values of the dynamic parts of the elongated tubular acoustic resonators $R'$ and $R''$ viscous attached vibrating masses of the air column at their open end sections. At the same time, temperature changes of the atmosphere (air) $\Delta t^\circ C$ make a definite influence on the of acoustic resonators $R$ function effectiveness. At constant sound radiation frequency, this leads to a corresponding change in sound waves spreading velocity values and the acoustic wavelength $\lambda$. Thus, in these cases the condition of effective process of sound wave interferential antiphase amplitude compensation can be offended, as a result of a dynamic equation mismatch of used wavelength ($\lambda'_{R}$, $\lambda''_{R}$) of the tubular parts of acoustic resonators $R'$ and $R''$ wavelength quarters ($\lambda/4$) or halves of the length ($\lambda/2$) of sound waves, distributed there.

For this reason it is proposed to take into account the specific values of the ambient temperature $t^\circ C$ distribution of sound waves in the process of temperature-adapted frequency tuning of acoustic resonators $R'$ and $R''$ (specified choice of geometric lengths of tubular parts $l$), which can be performed on expressions (1) and (2):

$$ l''_r = \frac{5.025 \cdot 273 + t^\circ C_{st}}{f_R} \cdot (0.1...0.3) \cdot \frac{4S_T}{\pi}, m \quad (1) $$

$$ l'_r = \frac{10.105 \cdot 273 + t^\circ C_{st}}{f_R} \cdot (0.2...0.6) \cdot \frac{4S_T}{\pi}, m \quad (2) $$

where $l'_r$, $l''_r$ - geometrical (overall) length of the tubular parts of acoustic resonators $R'$ and $R''$;

$t^\circ C_{st}$ - stable (set) the value of air temperature in $^\circ C$ inside the room (building) of closed type electrical transformer substation;

$f_R$ - acoustic resonator $R$ ($R'$, $R''$, $R'''$) natural (resonant) frequency in Hz;

$S_T$ - area in $m^2$ of passage section of the tubular portion of the acoustic resonator $R$ ($R'$, $R''$, $R'''$); $\pi = 3.14$.

Therefore, by setting the appropriate values $f_R$ equal to $f_1, f_2$ and $f_3$ in the expressions (1) and (2), we will define a specific geometrical length of the tubular parts of acoustic resonators $R_1, R_2, R_3$ - $l'_r$ and $l''_r$, for the given parameters $S_T, t^\circ C_{st}$ and $\pi$.

In the similar way we can consider the use of a Helmholtz resonator $R'''$ ($R_1'''$, $R_2'''$, $R_3'''$), being set on the same operating frequency function $f_1 = 100$ Hz, $f_2 = 200$ Hz and $f_3 = 300$ Hz, which dominate in the power electric transformer sound radiation spectrum, powered from the AC with a frequency $f_{AC}$ (see. Fig. 2c). In this case, their resonant frequencies $f'_{R1'''}$, $f'_{R2'''}$, $f'_{R3'''}$ are determined according to expressions (3) and (4):

$$ f''_{R} = \frac{20.1 \sqrt{273 + t^\circ C_{st}}}{2\pi} \cdot \frac{k}{\sqrt{V_k}}, Hz \quad (3) $$

$$ k = \frac{n_{hole} \cdot F_{hole}}{l''_R} = \frac{n_{hole} \cdot F_{hole}}{(h + 0.8 \sqrt{F_{hole}})} \quad (4) $$

where $k$ - throat conductivity (throat portion) of a Helmholtz resonator $R'''$ ($R_1'''$, $R_2'''$, $R_3'''$) in m;
\( V_k \) - the chamber volume of a Helmholtz resonator \( R''' \) (\( R_1'''', R_2'''', R_3'''' \)) in \( \text{m}^3 \);

\( F_{\text{hole}} \) - cross sectional area in \( \text{m}^2 \) of perforation hole as a part of the throat (throat portion) of a Helmholtz resonator \( R''' \) (\( R_1'''', R_2'''', R_3'''' \));

\( n_{\text{hole}} \) - number of perforation holes, forming a neck portion of a Helmholtz resonator \( R''' \) (\( R_1'''', R_2'''', R_3'''' \)) when there is an option of the neck portion implementation by multiple \( (n_{\text{hole}}) \) perforations;

\( h''' \) - geometrical length in \( \text{m} \) (wall thickness of the body portion in the area of implementation of one of \( n_{\text{hole}} \) perforations, being a part of the neck portion of a Helmholtz resonator \( R''' \) (\( R_1'''', R_2'''', R_3'''' \));

\( l_{R''''} \) - a Helmholtz resonator \( R''' \) neck portion dynamic length in \( \text{m} \), presented by several \( n_{\text{hole}} \) perforation holes in consideration of the extension of the geometric length \( h''' \), viscous attached to the neck portion of the oscillating air masses perforation unit.

To eliminate the frequency detuning of the classical type of acoustic resonators \( R', R'', R''' \) from the physical impact of external factors, into various types of dissipative elements of active resistance, reducing the quality factor of the frequency characteristics at the resonance frequency \( f_R \) can be integrated in their design. In this case, it may be achieved by expanding the operating frequency range of the functionality at decrease of the amplitude values suppression, directly on the resonant frequency \( f_R \). There is also the beneficial reducing effects of spurious side resonant amplifications of sound vibrations in the near-resonance zones on both sides of the discrete frequency resonance \( f_R \). As dissipative elements of modification improvement of acoustic resonators structures \( R', R'', R''' \) perforation via openings can be used, made in certain areas of the walls of the tubular parts, porous air-swept plugs, placed in certain areas of the cavity of the tubular parts, protective air footer air-swept layers of material, mounted on the neck portion and / or the perforated wall portions of the tubular parts and / or perforated portions of the acoustic resonator chamber \( R', R'', R''' \) (see. Fig. 2).

The use of the automated system of room (building) air cavity thermostatic of closed type electrical substation (hereinafter - the room), containing electrically controlled cooling fan installation of the active part of the power electric transformers, helps to improve the functioning of acoustic resonators \( R \). This electrical fan installation can work in automatic modes of discrete "Enabling - Disabling" or modulating control of operational speed mode (performance), thereby providing a predetermined narrow range of ambient air in the room, while maintaining an efficient frequency-temperature-adapted configuration of the acoustic resonators \( R \).

Acoustic Resonators \( R', R'', R''' \) are to be mounted primarily inside of room ducts cavities (should be placed on the walls of the duct and the cavity of the ventilation system expansion chamber), as well as room wall and ceiling structures, its front door. This is due to the fact that the open vents are main sound transmission waveguide elements, through which the acoustic pollution is carried out.

Also, the individual blocks of acoustic resonators \( R \) can be mounted directly on the noise generating structural and / or the individual functional units and systems of power electric transformers (oil tank walls, the reference profile of the elements of the frame and the mounting frame, housing electric fan installation). The fixing of acoustic resonator \( R \) structures to thin-walled vibrating noise active elements of specified nodes and systems of electrical transformer substation can be done with using of an intermediate viscoelastic vibration and noise damping layer, what allows them to provide effective damping of mechanical vibrations and reduce structural (corpus) noise radiation.

**Conclusion**

The abovementioned constructive schemes of modified frequency tuned thermally adapted acoustic resonators \( R \) (quarter - \( R' \), half-wavelength \( R'' \), the Helmholtz \( R''' \)) can be used for effective suppress of acoustic energy, generated by the active part of the power electrical transformers. Thus, we can reach the reduction of acoustic pollution from noise-active structures of power electrical transformers, which are using electrical steels with improved magnetic properties, characterized by high magnetostriction and noise-generating intense.
Nomenclature

1. power electrical transformer
2. foundation base
3. enclosing wall panels (wall partitions), floor, the ceiling (roof)
4. quarter wave acoustic resonators R'
5. half-wave acoustic resonators R"
6. Helmholtz resonator R'''
7. vents (channels), premises (buildings)
8. tubular portion
9. the bottom part (acoustically reflective rigid bedplate)
10. perforation holes
11. air-swept damping porous plug
12. a throat part
13. protective footer snubber air-swept layer
14. a chamber part

References